CLAIMS

1. A method of correcting a digital representation of an x-ray image for degradation caused by a digitiser, the digital representation being a measurement of the image density for each of a plurality of pixels of the image, the measurement being obtained by illuminating the image, measuring the attenuation of the light by the image and calculating from the attenuated light values the image density, the method comprising the steps of:

calculating from the pixel values in the digital representation the value of the intensity of said attenuated light corresponding to each pixel;

applying to the intensity values a modulation transfer function to correct for the degradation introduced by the digitiser; and

converting the corrected intensity values back into values representative of the image intensity.

2. A method according to claim 1, wherein the modulation transfer function corrects for blur and the digitising aperture.

3. A method according to claim 1 or 2, wherein the intensity T_i of the attenuated light is calculated as: $T_i=I_i \times 10^{-D}$, where I_i is the intensity of the illumination of the image and D is the value of the image density in the digital representation, and the corrected intensity values T_i' are converted back into values D' representative of the image intensity by: $D' = log(I_i/T_i')$.

4. Apparatus for correcting a digital representation of an x-ray image for degradation caused by a digitiser, the digital representation being a measurement of the image density for each of a plurality of pixels of the image, the measurement being obtained by illuminating the image, measuring the attenuation of the light by the image and calculating from the attenuated light values the image density, the apparatus comprising:

calculating means for calculating from the pixel values in the digital representation the value of the intensity of said attenuated light corresponding to each pixel;

correction means for applying to the intensity values a modulation transfer function to correct for the degradation introduced by the digitiser; and

conversion means for converting the corrected intensity values back into values representative of the image intensity.

5. Apparatus according to claim 4, wherein the conversion means corrects for blur and the digitising aperture.

6. Apparatus according to claim 3 or 4, wherein the calculation means calculates intensity T_i of the attenuated light as: $T_i = I_i \times 10^{-D}$, where I_i is the intensity of the illumination of the image and D is the value of the image density in the digital representation, and the conversion means converts the corrected intensity values T_i' back into values D' representative of the image intensity by: $D' = log(I_i/T_i')$.

7. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to correct a digital representation of an x-ray image for degradation caused by a digitiser, the digital representation being a measurement of the image density for each of a plurality of pixels of the image, the measurement being obtained by illuminating the image, measuring the attenuation of the light by the image and calculating from the attenuated light values the image density, by a method comprising the steps of:

calculating from the pixel values in the digital representation the value of the intensity of said attenuated light corresponding to each pixel;

applying to the intensity values a modulation transfer function to correct for the degradation introduced by the digitiser; and

converting the corrected intensity values back into values representative of the image intensity.

8. A computer program storage medium according to claim 7, wherein the modulation transfer function corrects for blur and the digitising aperture.

9. A computer program storage medium according to claim 7 or 8, wherein the intensity T_I of the attenuated light is calculated as: $T_I=I_I x\ 10^{-D}$, where I_I is the intensity of the illumination of the image and D is the value of the image density in the digital representation, and the corrected intensity values T_I' are converted back into values D' representative of the image intensity by: $D' = log(I_I/T_I')$.

10. In a method of x-ray imaging using an intensifying screen to receive x-rays and emit light to be recorded on an x-ray film, a method of calculating from the film image density the energy which was imparted to the intensifying screen, comprising the steps of:

calibrating the film and intensifying screen by measuring the response of the film and intensifying screen to a plurality of different intensities of received x-rays;

fitting a theoretical model of the expected response to the measured response, and using the fitted theoretical model to calculate the imparted energy from the image density.

11. A method according to claim 10, wherein the theoretical model is a serpentine curve of the form:

$$x^2y + a^2y - b^2x = 0,$$

where a and b are constants, x is the logarithm of the energy imparted to the intensifying screen and y is the image density.

12. A method according to claim 10 or 11, wherein the response of the film and intensifying screen to a plurality of different intensities of received x-rays is measured by exposing the film-screen combination to x-rays through a lucite step wedge and measuring the image density produced by the exposure through the different steps of the wedge.

13. Apparatus for calculating from image densities of an x-ray film image the energy which was imparted to an intensifying screen used to receive x-rays and emit light to be recorded on the x-ray film, the apparatus comprising:-

fitting means for fitting a theoretical model of the expected response of the x-ray film

and intensifying screen to a plurality of different intensities of received x-rays to a measured response, and

calculation means for using the fitted theoretical model to calculate the imparted energy from the image density.

14. Apparatus according to claim 13, wherein the theoretical model is a serpentine curve of the form:

$$x^2y + a^2y - b^2x = 0,$$

where a and b are constants, x is the logarithm of the energy imparted to the intensifying screen and y is the image density.

15. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to calculate from image densities of an x-ray film the energy which was imparted to an intensifying screen used to receive x-rays and emit light recorded on the x-ray film, by a method comprising the steps of:

fitting a theoretical model of the expected response of the x-ray film and intensifying screen to a plurality of different intensities of received x-rays to a measured response, and using the fitted theoretical model to calculate the imparted energy from the image density.

16. A computer program storage medium according to claim 15, wherein the theoretical model is a serpentine curve of the form:

$$x^2y + a^2y - b^2x = 0,$$

where a and b are constants, x is the logarithm of the energy imparted to the intensifying screen and y is the image density.

17. In a method of x-ray imaging in which an intensifying screen is used to

receive x-rays and emit light to be recorded on an x-ray, the image recorded on the film is digitised to give a pixelised digital representation of the image density on the film, a method of enhancing the digital representation of the image to remove the contribution thereto of glare from the intensifying screen comprising the steps of:

converting the digital representation of image density into a representation of the energy imparted to the screen; and

deconvolving the representation of the energy imparted to the screen using a weighting mask defining the point spread function for the intensifying screen to remove the contribution thereto of glare from the intensifying screen.

18. A method according to claim 17, wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels weighted by distance from the absorption site to the pixel.

19. A method according to claim 18 , wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels further weighted by the depth of the absorption site in the intensifying screen.

20. A method of detecting film-screen shot noise in a x-ray image in which an intensifying screen is used to receive x-rays and to emit light to be recorded as an image on a x-ray film, the image recorded on the film being digitised to give a pixelised digital representation thereof which is then converted into a representation of the energy imparted to the screen, the method comprising removing from that representation glare from the intensifying screen in accordance with the method of claim 17, and defining as film-screen shot noise regions of the image in which the resultant value for energy imparted to the screen is infeasible.

21. A method according to claim 20, wherein regions of the image in which resultant values for energy imparted to the screen having negative values are defined as film-

screen shot noise.

22. A method according to claim 20 or 21, wherein the image is a mammogram.

23. Apparatus for enhancing the digital representation of an x-ray image obtained by using an intensifying screen to receive x-rays and emit light to be recorded on an x-ray film and digitising the film to give a pixelised digital representation of the image density thereon the apparatus comprising:

conversion means for converting the digital representation of image density into a representation of the energy imparted to the screen; and

deconvolution means for deconvolving the representation of the energy imparted to the screen using a weighting mask defining the point spread function for the intensifying screen to remove the contribution thereto of glare from the intensifying screen.

24. Apparatus according to claim 23, wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels weighted by distance from the absorption site to the pixel.

25. Apparatus according to claim 24 , wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels further weighted by the depth of the absorption site in the intensifying screen.

26. Apparatus for detecting film-screen shot noise in a x-ray image obtained by using an intensifying screen to receive x-rays and to emit light to be recorded as an image on an x-ray film, the image recorded on the film being digitised to give a pixelised digital representation thereof which is then converted into a representation of the energy imparted to the screen, the apparatus comprising apparatus according to claim 23, 24 or 25 for removing from that representation glare from the intensifying screen, and means for defining as film-screen shot noise regions of the image in which the resultant value for energy imparted to the

screen is infeasible.

27. Apparatus according to claim 26, wherein regions of the image in which resultant values for energy imparted to the screen having negative values are defined as film-screen shot noise.

28. Apparatus according to claim 26 or 27, wherein the image is a mammogram.

29. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to enhance the digital representation of an x-ray image obtained by using an intensifying screen to receive x-rays and emit light to be recorded on an x-ray film, the image recorded on the film being digitised to give a pixelised digital representation of the image density thereon, the removal from the digital representation of the image of the contribution thereto of glare from the intensifying screen comprising the steps of:

converting the digital representation of image density into a representation of the energy imparted to the screen; and

deconvolving the representation of the energy imparted to the screen using a weighting mask defining the point spread function for the intensifying screen to remove the contribution thereto of glare from the intensifying screen.

30. A computer program storage medium according to claim 29, wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels weighted by distance from the absorption site to the pixel.

31. A computer program storage medium according to claim 30 , wherein the weighting mask defines the contribution to the energy imparted to the screen caused by the emission of light from the point of absorption of an x-ray towards neighbouring pixels further weighted by the depth of the absorption site in the intensifying screen.

32. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to detect film-screen shot noise in a x-ray image obtained by using an intensifying screen to receive x-rays and to emit light to be recorded as an image on an x-ray film, the image recorded on the film being digitised to give a pixelised digital representation thereof which is then converted into a representation of the energy imparted to the screen, the detection of film-screen shot noise comprising removing from that representation glare from the intensifying screen in accordance with claim 29, and defining as film-screen shot noise regions of the image in which the resultant value for energy imparted to the screen is infeasible.

33. A computer program storage medium according to claim 32, wherein regions of the image in which resultant values for energy imparted to the screen having negative values are defined as film-screen shot noise.

34. A computer program storage medium according to claim 32 or 33, wherein the image is a mammogram.

35. A method of calculating from a mammogram the compressed thickness of the imaged breast, comprising the step of delimiting in the mammogram the region corresponding to the part of the breast which is compressed from the region corresponding to the uncompressed breast edge by detecting the smoothness of curves of equal intensity in the mammogram.

36. A method according to claim 35, further comprising the steps of detecting the smooth equal intensity curve which is positioned furthest from the breast edge, calculating from the intensities along that curve the thickness of fat in the breast which gives those intensities, and calculating the thickness of the compressed breast from that thickness of fat.

37. A method according to claim 35 or 36, comprising as an initial step the conversion of the mammogram into the h_{int} representation representing the thicknesses of fat and interesting tissue in regions of the breast contributing to each point in the mammogram.

38. A method according to claim 37, wherein the conversion is performed on the basis of an underestimate of the compressed breast thickness, the conversion being iterated with successively changing estimates of the compressed breast thickness until a smooth delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge is found.

39. A method according to any one of claims 35 to 38, wherein a predefined smoothness threshold is set to detect the smooth curves.

40. A method of calculating the contribution to a mammogram of extra-focal radiation by calculating the compressed thickness of the imaged breast according to the method of any one of claims 35 to 39, calculating from the x-ray exposure and an estimate of the scattering of radiation the expected intensity in the mammogram along the delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge, and comparing the expected intensity to the actual intensity in the mammogram.

41. Apparatus for calculating from a mammogram the compressed thickness of the imaged breast, comprising means for delimiting in the mammogram the region corresponding to the part of the breast which is compressed from the region corresponding to the uncompressed breast edge by detecting the smoothness of curves of equal intensity in the mammogram.

42. Apparatus according to claim 41, further comprising detection means to detect the smooth equal intensity curve which is positioned furthest from the breast edge, and calculating means for calculating from the intensities along that curve the thickness of fat in the breast which gives those intensities, and for calculating the thickness of the compressed breast from that thickness of fat.

43. Apparatus according to claim 41 or 42, comprising conversion means for converting the mammogram into the h_{int} representation representing the thicknesses of fat and

interesting tissue in regions of the breast contributing to each point in the mammogram.

44. Apparatus according to claim 43, wherein the conversion means first underestimates the compressed breast thickness, and iterates the conversion with successively changing estimates of the compressed breast thickness until a smooth delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge is found.

45. Apparatus according to any one of claims 41 to 44, wherein a predefined smoothness threshold is set to detect the smooth curves.

46. Apparatus for calculating the contribution to a mammogram of extra-focal radiation comprising apparatus according to any one of claims 41 to 45 for calculating the compressed thickness of the imaged breast, and further comprising expected intensity calculating means for calculating from the x-ray exposure and an estimate of the scattering of radiation the expected intensity in the mammogram along the delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge, and comparing means for comparing the expected intensity to the actual intensity in the mammogram.

47. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to calculate from a mammogram the compressed thickness of the imaged breast by a method comprising the step of delimiting in the mammogram the region corresponding to the part of the breast which is compressed from the region corresponding to the uncompressed breast edge by detecting the smoothness of curves of equal intensity in the mammogram.

48. A computer program storage medium according to claim 47, wherein the method further comprises the steps of detecting the smooth equal intensity curve which is positioned furthest from the breast edge, calculating from the intensities along that curve the thickness of fat in the breast which gives those intensities, and calculating the thickness of the

compressed breast from that thickness of fat.

49. A computer program storage medium according to claim 47 or 48, wherein the method further comprises as an initial step the conversion of the mammogram into the h_{int} representation representing the thicknesses of fat and interesting tissue in regions of the breast contributing to each point in the mammogram.

50. A computer program storage medium according to claim 49, wherein the conversion is performed on the basis of an underestimate of the compressed breast thickness, the conversion being iterated with successively changing estimates of the compressed breast thickness until a smooth delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge is found.

51. A computer program storage medium according to any one of claims 47 to 50, wherein a predefined smoothness threshold is set to detect the smooth curves.

52. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to calculate the contribution to a mammogram of extra-focal radiation by calculating the compressed thickness of the imaged breast according to the method of any one of claims 35 to 40, calculating from the x-ray exposure and an estimate of the scattering of radiation the expected intensity in the mammogram along the delimitation between the region corresponding to the part of the breast which is compressed and the region corresponding to the uncompressed breast edge, and comparing the expected intensity to the actual intensity in the mammogram.

53. A method of processing a mammogram to produce an h_{int} representation representing the thicknesses of fat and interesting tissue in regions of the breast contributing to each point in the mammogram, the mammogram being produced by using an intensifying screen to receive x-rays transmitted through the breast and to emit light to be recorded as the mammogram on an x-ray film, the mammogram being digitised by a digitiser to obtain a

digital representation thereof comprising pixel values representing the image intensities in the mammogram, the method comprising the steps of:

correcting the digital representation for degradation caused by the digitiser according to the method of any one of claims 1 to 3;

converting the values in the digital representation to values representing the energy which was imparted to the intensifying screen according to the method of any one of claims 10 to 12;

compensating the converted values for glare from the intensifying screen according to the method of any one of claims 12 to 22;

further compensating the values for variations in intensity of the x-ray beam incident on the breast;

calculating the compressed thickness of the imaged breast according to the method of any one of claims 35 to 39;

calculating the contribution to the mammogram of extra-focal radiation according to the method of claim 40;

subtracting from the compensated values the extra-focal radiation and an estimate of the scattered radiation to give enhanced measured values of the energy which was imparted to the intensifying screen; and

calculating the h_{int} representation by equating the enhanced measured values with predicted values.

54. A method according to claim 53, wherein the predicted values are calculated from the intensity of x-rays incident on the breast and the absorption characteristics of physical elements of the imaging system.

55. Apparatus for processing a mammogram to produce an h_{int} representation representing the thicknesses of fat and interesting tissue in regions of the breast contributing to each point in the mammogram, the mammogram being produced by using an intensifying screen to receive x-rays transmitted through the breast and to emit light to be recorded as the mammogram on an x-ray film, the mammogram being digitised by a digitiser to obtain a digital representation thereof comprising pixel values representing the image intensities in the

mammogram, the apparatus comprising:

apparatus for correcting the digital representation for degradation caused by the digitiser according to any one of claims 4 to 6;

apparatus for calculating from the values in the digital representation values representing the energy which was imparted to the intensifying screen according to claim 13 or 14;

apparatus for compensating the converted values for glare from the intensifying screen according to any one of claims 23 to 28;

means for further compensating the values for variations in intensity of the x-ray beam incident on the breast;

apparatus for calculating the compressed thickness of the imaged breast according to any one of claims 41 to 45

apparatus for calculating the contribution to the mammogram of extra-focal radiation according to claim 46;

subtraction means for subtracting from the compensated values the extra-focal radiation and an estimate of the scattered radiation to give enhanced measured values of the energy which was imparted to the intensifying screen; and

h_{int} calculating means for calculating the h_{int} representation by equating the enhanced measured values with predicted values.

56. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to process a mammogram to produce an h_{int} representation representing the thicknesses of fat and interesting tissue in regions of the breast contributing to each point in the mammogram, the mammogram being produced by using an intensifying screen to receive x-rays transmitted through the breast and to emit light to be recorded as the mammogram on an x-ray film, the mammogram being digitised by a digitiser to obtain a digital representation thereof comprising pixel values representing the image intensities in the mammogram, by a method comprising the steps of:

correcting the digital representation for degradation caused by the digitiser according to the method of any one of claims 1 to 3;

converting the values in the digital representation to values representing the energy

which was imparted to the intensifying screen according to the method of any one of claims 10 to 12;

compensating the converted values for glare from the intensifying screen according to the method of any one of claims 12 to 22;

further compensating the values for variations in intensity of the x-ray beam incident on the breast;

calculating the compressed thickness of the imaged breast according to the method of any one of claims 35 to 39;

calculating the contribution to the mammogram of extra-focal radiation according to the method of claim 40;

subtracting from the compensated values the extra-focal radiation and an estimate of the scattered radiation to give enhanced measured values of the energy which was imparted to the intensifying screen; and

calculating the h_{int} representation by equating the enhanced measured values with predicted values.

57. A method of detecting microcalcifications in a breast from a mammogram of the breast, comprising the steps of processing the mammogram to produce an h_{int} representation according to the method of claim 53 or 54, converting the value of h_{int} for a candidate region into a value representative of the volume of interesting tissue and thresholding the volume values to detect as microcalcifications areas of the mammogram where the volume value exceeds a threshold.

58. A method according to claim 57 wherein the value of the volume of interesting tissue is compared to an estimate of the actual volume of the candidate region.

59. A method according to claim 57 or 58 wherein the volume values are calculated after subtraction from the h_{int} value of an estimate of the background h_{int}.

60. Apparatus for detecting microcalcifications in a breast from a mammogram of the breast, comprising apparatus for processing the mammogram to produce an h_{int}

representation according to claim 55, means for converting the value of h_{int} for a candidate region into a value representative of the volume of interesting tissue and means for thresholding the volume values to detect as microcalcifications areas of the mammogram where the volume value exceeds a threshold.

61. Apparatus according to claim 60 further comprising means for comparing the value of the volume of interesting tissue to an estimate of the actual volume of the candidate region.

62. Apparatus according to claim 60 or 61 further comprising means for subtracting from the h_{int} value an estimate of the background h_{int}, before calculating the volume values.

63. A computer program storage medium readable by a computer system and encoding a computer program for controlling a computer to detect microcalcifications in a breast from a mammogram of the breast by a method comprising the steps of processing the mammogram to produce an h_{int} representation according to the method of claim 53 or 54, converting the value of h_{int} for a candidate region into a value representative of the volume of interesting tissue and thresholding the volume values to detect as microcalcifications areas of the mammogram where the volume value exceeds a threshold.

64. A computer program storage medium according to claim 63 wherein the value of the volume of interesting tissue is compared to an estimate of the actual volume of the candidate region.

65. A program storage medium according to claim 63 or 64 wherein the volume values are calculated after subtraction from the h_{int} value of an estimate of the background h_{int}.

66. A method of processing a mammogram substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.